UCRL-ID-150286

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

Microstructural Origins of Dynamic Fracture in Ductile Metals

R. Becker, J. Belak, G. Campbell

December 16, 2002

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Title: Microstructural Origins of Dynamic Fracture in Ductile Metals

Tracking No.: 01-ERD-022

Principle Investigator:	James Belak
Division:	H-Division / PAT
Phone:	x2-6061
Mail Station:	L-45
Co-investigators:	J. Cazamias (PAT/H), M. Fivel (Grenoble), D. Haupt (ENG/MMED), J. Kinney (ENG/MMED), M. Kumar (CMS), R. Minich (DNT/B), R. Rudd (PAT/H), A. Schwartz (CMS),

From the formation of microscopic cracks in the fuel pipe liner of the space shuttle to the safety of roadway bridges, the fracture of materials has enormous implications throughout our society. The ability to assess and design safe engineering structures requires a detailed knowledge of this failure process. The fracture process depends on both the loading history and the detailed microscopic structure (microstructure) of the material. Weak points, such as inclusions and grain boundary junctions, are the locations from which microscopic fractures (voids and cracks) originate. Once nucleated, these fractures quickly link together to form a macroscopic crack. Despite this qualitative understanding, little is known about voids nucleation, plastic deformation in the surrounding material, and the mechanisms of linking.

Central to Stockpile Stewardship is an understanding of shock loading of materials. During the passage of a shock wave, the material is compressed at a very high rate. This compression produces a high density of dislocation defects and other changes to the microstructure that are poorly understood. When the shock wave reflects from a free surface, the compression is rapidly released and extreme tension is produced inside the material. If this tension exceeds the internal rupture strength, microscopic fractures form and link up to create a spallation scab---a thin scab that separates from the bulk of the material.

In this project, we use the LLNL gas gun facility to produce a planar stress pulse with controlled duration and amplitude. The sample is carefully captured in soft foam while measuring the free surface velocity profile. The amount of change in the surface velocity during release is related to the spallation strength. We study light metals (Al, V, Ti, Cu) with known initial microstructure: single crystal, polycrystalline, and single crystal with engineered inclusions. Light metals enable direct measurement of the three dimensional distribution of damage using X-Ray tomography. After the tomography experiment is complete, the samples are sliced and analyzed using 2D metallography.

During FY2002, we continued our study of polycrystalline Al and completed a study on pure single crystal Al. These samples were scanned at SSRL and 3D X-Ray tomographic images produced. The resulting image for single crystal Al shocked at 166m/s along the [011] direction is shown in the Figure. In contrast to our polycrystalline studies, we find a bimodal distribution of well separated voids. Many of the voids are faceted, consistent with our direct numerical simulations of void growth. Shown in the inset is a 2D metallographic image of one of the large voids. The halo in the metal surrounding the void is revealed by the surface preparation process. The surface etches at a greater rate near a dislocation core resulting in a surface pit. The halo is a cloud of surface pits that demonstrate the high density of dislocations in the region surrounding the incipiently grown void. This is the first direct measurement of the plastically deformed zone in void growth. We have further analyzed this zone with Orientational Imaging Microscopy to reveal the direction of slip and Nanoindentation to reveal the enhanced hardness inside the zone. Transmission Electron Microscopy to reveal details of the dislocation structure is currently under way.

In FY2003, we will complete our study in BCC Vanadium, HCP Titanium, and FCC Copper with nanoscale (20nm) inclusions to make direct overlap with our numerical simulations.